# A practical approach to detect turn to turn shorts during superconductive magnet fabrication

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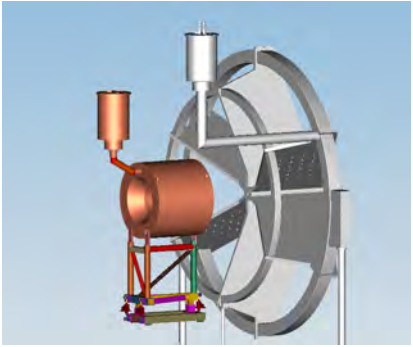
# CLAS12 for Hall B experiment

Six superconductive coils, forming a toroidal magnet, generate a toroidal magnetic field in order to deviate the debris coming from collisions between particles.
Each magnet is a double layered $Nb_3Sn$ coil with 117 turns per layer, winded, clamped and cured in Technical Division.



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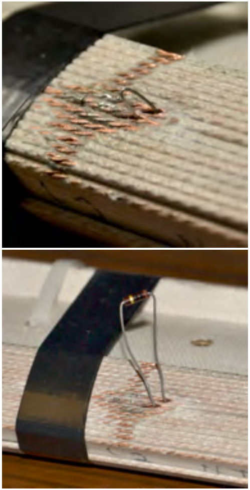

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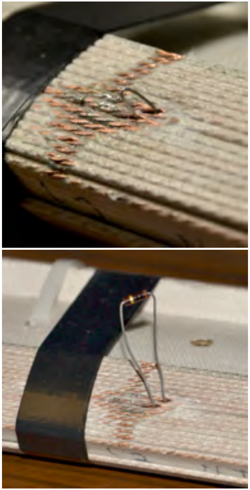

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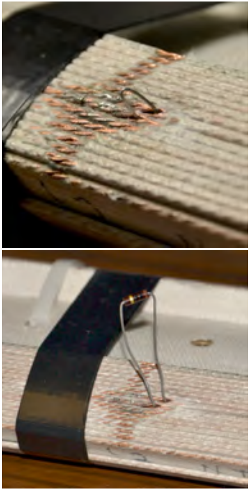

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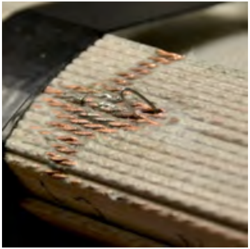

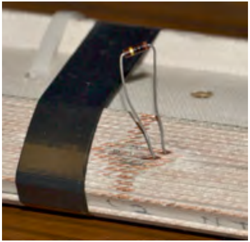

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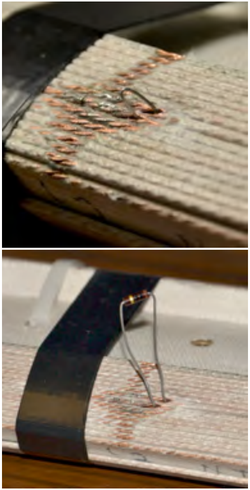

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- Simulated with resistors or wires (see pictures)

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Detect turn to turn shorts, both hard and as soft as possible.

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- Significant voltage drop between turns

# AC impedance analysis

Setup:

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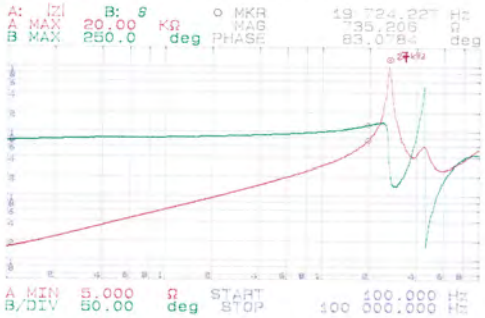


Figure: Double layered unclamped coil AC impedance

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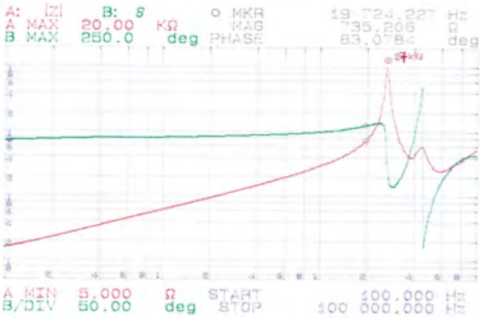


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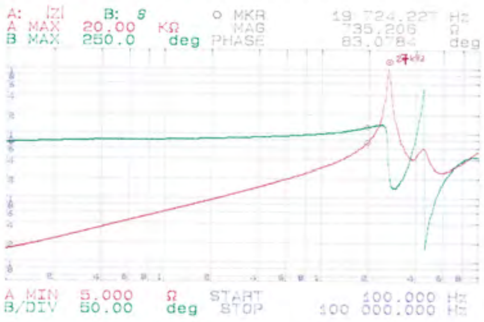


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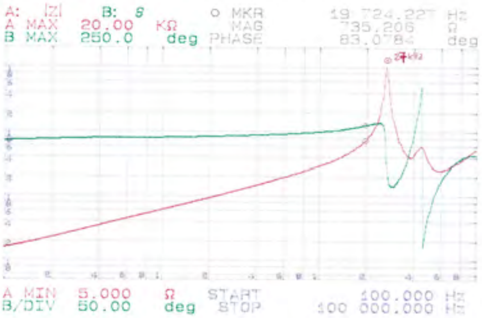


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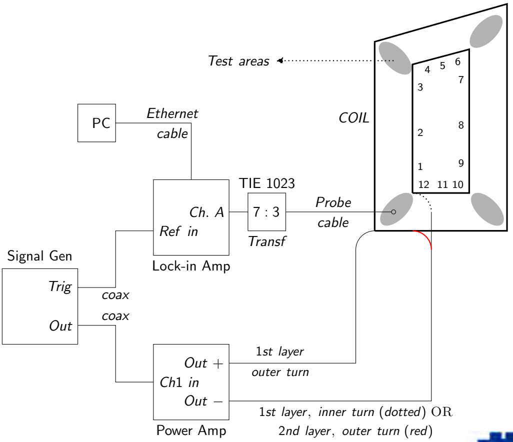

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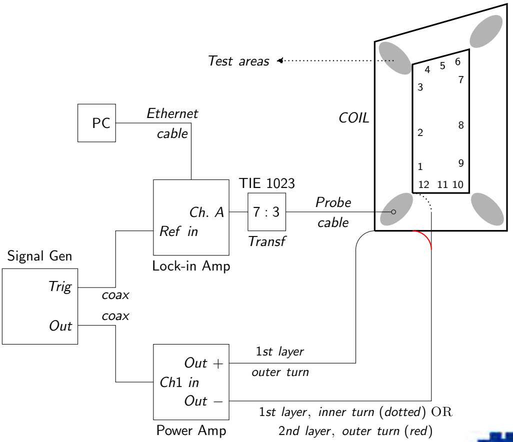

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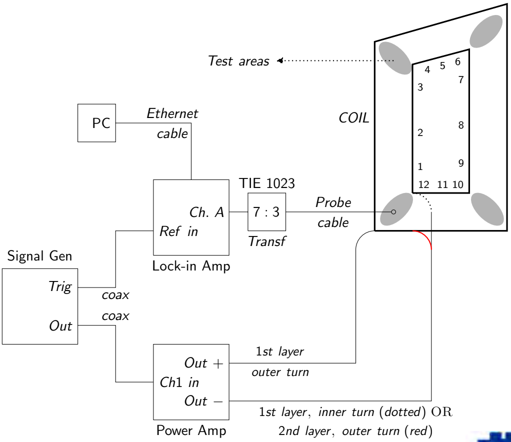

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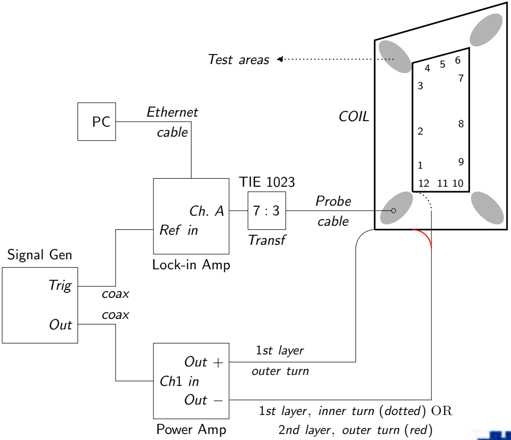

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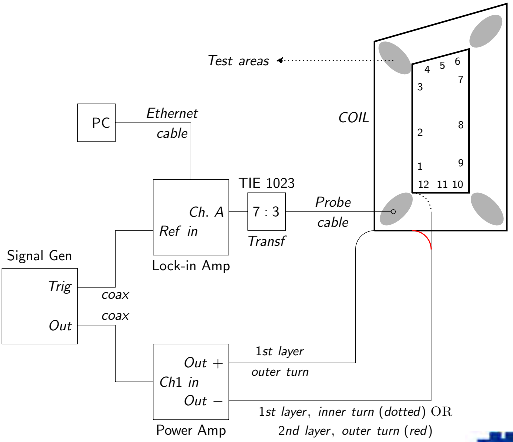
- Automatic data acquisition: LabView driver



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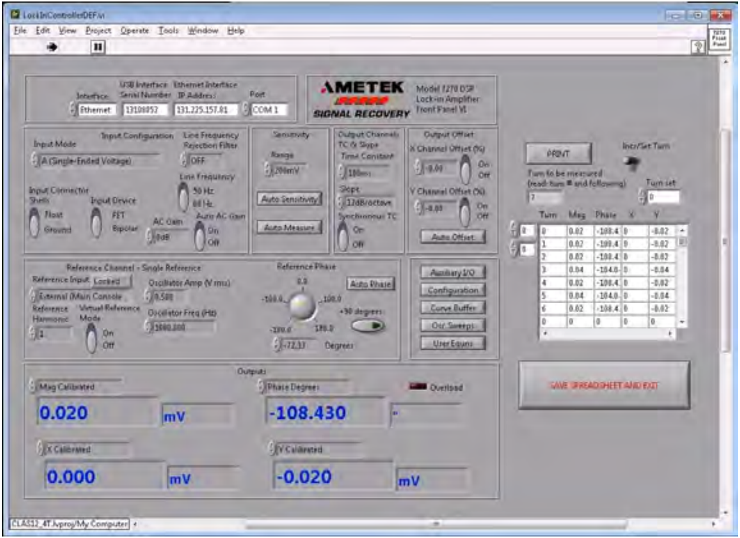
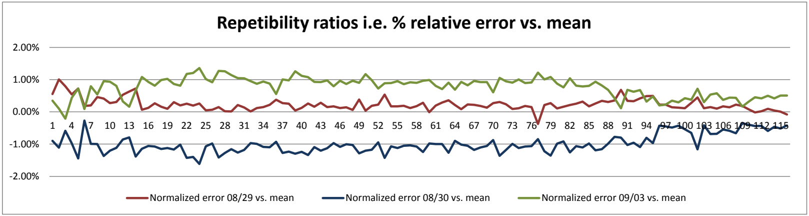
- Handmade transformer: more distant coils, high frequency wire, negligible parasitic effects


# LabView Driver



# Procedure

1. A few scannings of all turns, one position (corner 1-12), to see repeatability, that is the precision of the method



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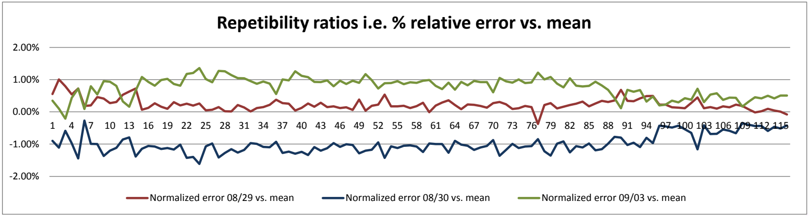
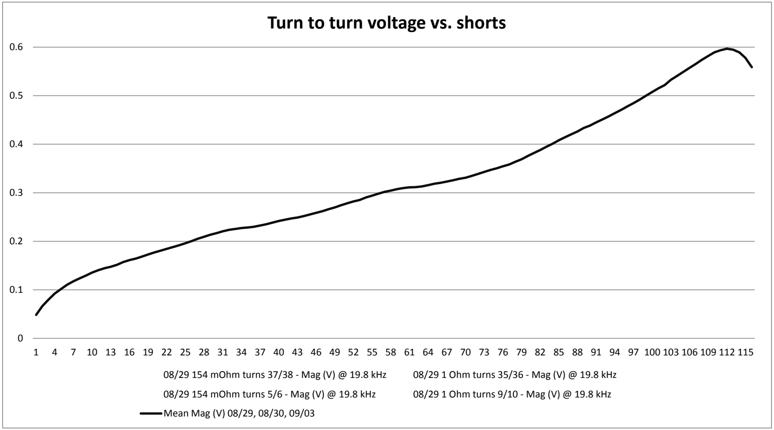
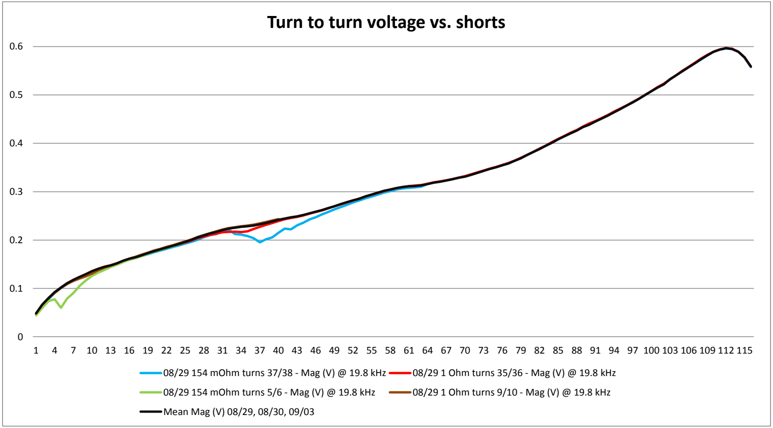
2. Scannings with different shorts to see position and amount of turn to turn voltage losses, that is the sensitivity and resolution of the method.



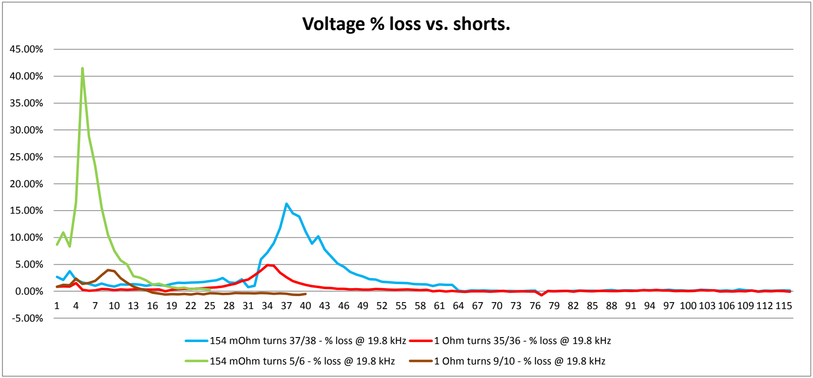
# Non shorted coil voltage curve



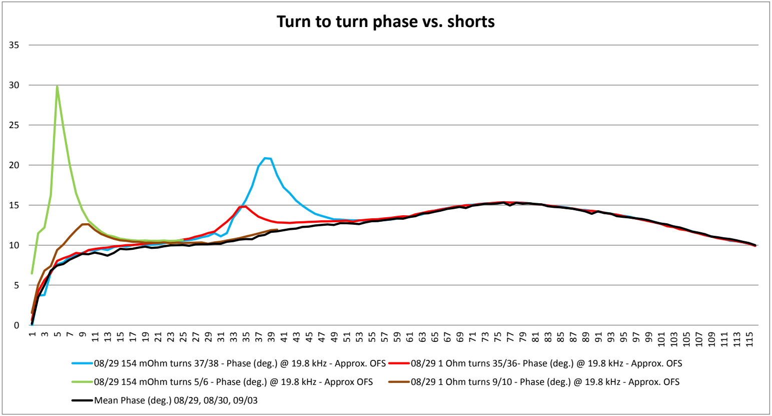
# Non shorted vs. shorted coil voltage curves



# Voltage losses

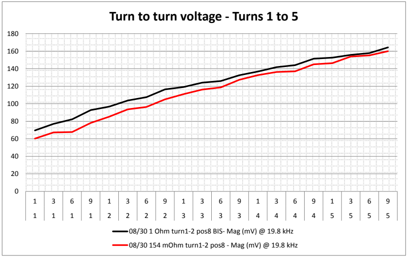


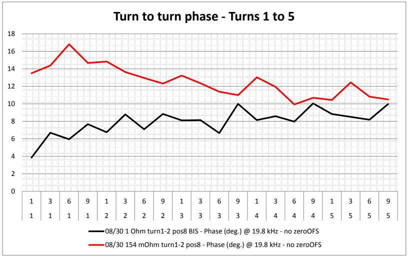
# Non shorted vs. shorted coil phase curves



# 4 position method

In the very first turns it is harder to see a sharp loss with a smooth bending by its sides. A 4-position scanning can help increase the resolution.




NB: with low SNR, the help of the phase is fundamental.

# Conclusions and problems

Resolution: up to 1 $\Omega$ in middle turns, up to a few hundreds $m\Omega$ in the first 5. But:

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2. Why should a short influence even the nearest turns?

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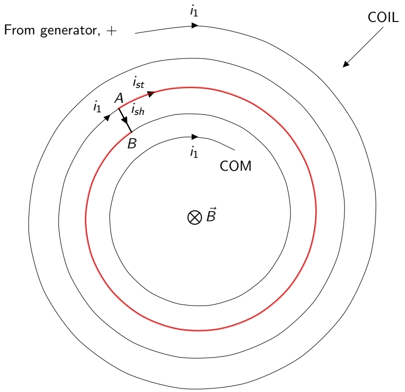
- Shorted turn (in red) is "bypassed"



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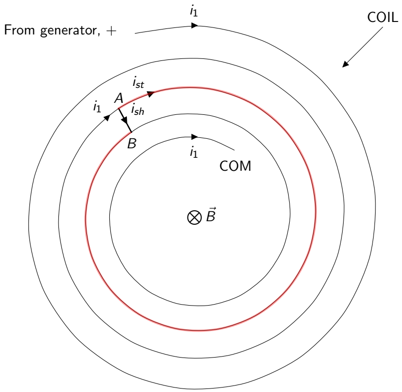

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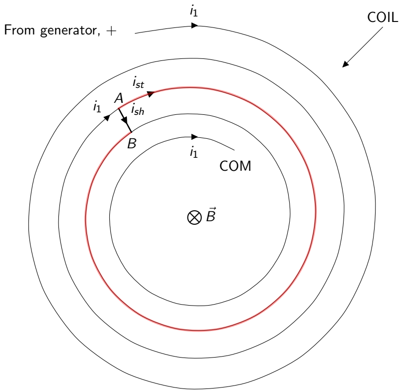

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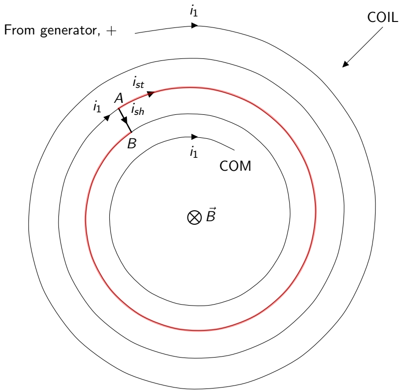

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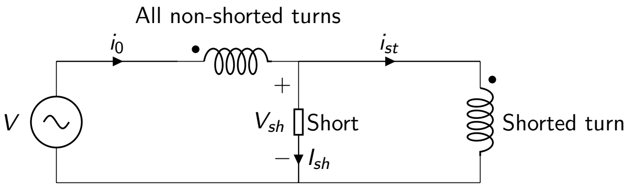

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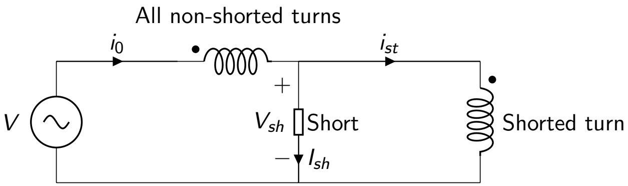


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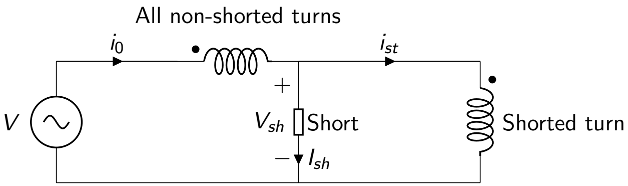


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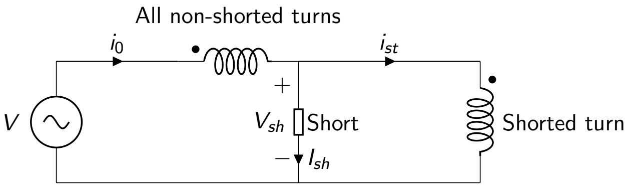


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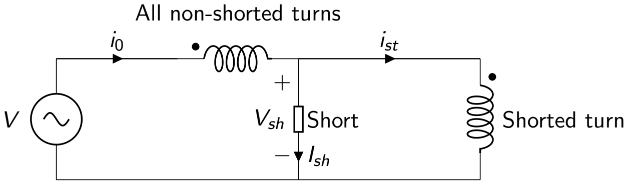


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> Despite this is a zero model, experimental data fit this theoretical result with good approximation.

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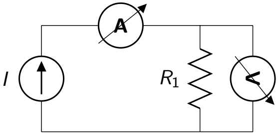
- "Enhanced 4W" needed: higher currents for very low resistances.

# Measuring the shunts

1. 3458A as ammeter, $I \approx 1\ A$ imposed, measured $R_1 \approx 1\ \Omega$ with 5 significant digits.



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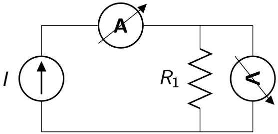


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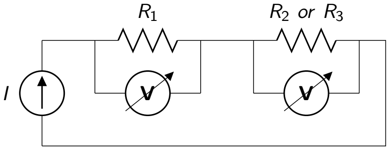

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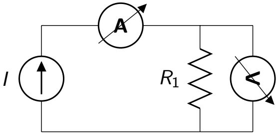


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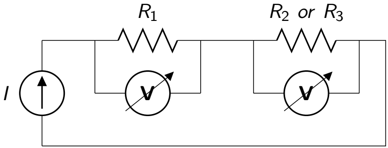
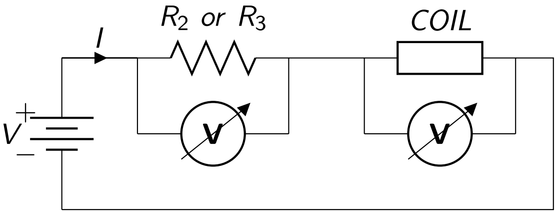



3. The same way with just $R_2$ and $R_3$ to double check their ratio at higher currents.

# Measuring the coil

4. Coil as load, $R_2$ and $R_3$ as shunts, currents from 1 to 10 $A$. Measured $R_{coil}$ with no less than 3 significant digits. NB: Voltage source used because current source did not work with reactive loads.



# Shunts

| Im avg | Va avg | Vb avg | Vc avg | Ra avg | Rb avg | Rc avg |
|---|---|---|---|---|---|---|
| 1.00538 | 1.00577 | 10.02065 | 0.9955 | ***1.000387913*** | ***9.967027393*** | ***0.99017287*** |
| 0.901365 | 0.90175 | 8.9885 | 0.8928 | 1.00042713 | 9.972097874 | 0.990497745 |
| 0.8944 | 0.89479 | 8.909 | 0.885 | 1.000436047 | 9.960867621 | 0.989490161 |
| 0.89587 | | 8.9345 | 0.8884 | | 9.972987152 | 0.991661737 |
| | | | | | | |
| | | | **Average:** | **1.00041703** | **9.967839188** | **0.99066020** |
| | | | **St. Dev.** | **0.00002091** | **0.003986671** | **0.00074192** |
| | | | **% St. Dev.** | **0.002090%** | **0.039995%** | **0.074891%** |
| | | | | | | |
| | | | Final values: | ***1.0004*** | ***9.968*** | ***0.991*** |

# Small test coil

| Vshunt (mV) | Rshunt (mOhms) | I meas (A) | Vcoil (mV) | R coil (mOhms) |
|---|---|---|---|---|
| 10.325 | 9.968 | 1.035814607 | 26.919 | 25.98824136 |
| 20.831 | 9.968 | 2.089787319 | 54.315 | 25.99068312 |
| 40.791 | 9.968 | 4.092195024 | 106.33 | 25.98361011 |
| 70.705 | 9.968 | 7.093198234 | 184.3 | 25.98263772 |
| 102.76 | 9.968 | 10.30898876 | 267.95 | 25.99188011 |
| 1.025 | 0.991 | 1.034308779 | 26.876 | 25.98450341 |
| 2.0755 | 0.991 | 2.094349142 | 54.397 | 25.97322428 |
| 4.062 | 0.991 | 4.09889001 | 106.46 | 25.97288528 |
| 7.045 | 0.991 | 7.108980827 | 184.65 | 25.97418737 |
| 10.224 | 0.991 | 10.31685166 | 268.1 | 25.98660994 |

| | |
|---|---|
| **Average:** | **25.98284627** |
| **St. Dev.** | **0.00675612** |
| **% St.Dev.** | **0.0260%** |

***R:*** ***25.98***

4 significant digits.

# CLAS12 coil

| Vshunt (mV) | Rshunt (mOhms) | I meas (A) | Vcoil (V) | R coil (mOhms) |
|---|---|---|---|---|
| 10.767 | 9.968 | 1.080156501 | 0.9124 | 844.692412 |
| 26.497 | 9.968 | 2.65820626 | 2.2447 | 844.4416198 |
| 65.198 | 9.968 | 6.540730337 | 5.5207 | 844.0494739 |
| 102.34 | 9.968 | 10.26685393 | 8.664 | 843.8807114 |
| 1.113 | 0.991 | 1.123107972 | 0.9484 | 844.4424079 |
| 2.589 | 0.991 | 2.612512614 | 2.205 | 844.0150637 |
| 6.211 | 0.991 | 6.26740666 | 5.2891 | 843.9056674 |
| 10.355 | 0.991 | 10.44904137 | 8.8176 | 843.8668856 |

| | |
|---|---|
| **Average:** | **844.1617802** |
| **St. Dev.** | **0.2967168** |
| **% St.Dev.** | **0.0351%** |
| ***R:*** | ***844*** |

3 significant digits, but St. Dev is much less than half of the last digit.

# A practical approach to detect turn to turn shorts during superconductive magnet fabrication

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